

CHRONOLOGY OF THE CONCEPT OF SYMMETRY AND ITS APPLICATIONS

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C. 600 B.C. Anaximander uses a symmetry argument to explain the stability of the world.

C. 250 B.C. Archimedes discusses the principle of the lever in his book 'On the equilibrium of planes'.

C. 1350 A.D. Buridan's Ass. A mediaeval sophism using a symmetry argument to ridicule the determinist views of Buridan (a similar conundrum was propounded by Aristotle in his work *De Caelo*).

1586 Stevinus derives the law of equilibrium on a double inclined plane.

1632 Galileo discusses invariance with respect to uniformly moving reference frames.

1703 Huyghens considers the laws of impact from the point of view of symmetry in his posthumous treatise 'De Motu Corporum ex Percussione'.

1713 Bernouilli introduces the Principle of Indifference in the theory of probability in his posthumous work 'Ars Conjectandi'.

1768 Kant uses a fallacious symmetry argument to disprove the relational theory of space.

1822 Fourier discusses the concept of scale invariance (also referred to by Galileo in 1638).

1828 Galois introduces symmetry groups in the study of algebraic equations (following earlier work by Lagrange and Ruffini).

1830 Hessel derives the 32 symmetry classes in crystallography

1845-1878 Cayley and Sylvester develop the theory of invariants of algebraic forms.

1848 Bravais analyses the 14 possible types of crystal lattice

1854 Cayley defines an abstract group.

1872 Klein's 'Erlanger Programm' expounds geometry as the study of symmetry.

1873-1893 Sophus Lie develops the theory of continuous groups.

1876 Loschmidt attacks Boltzmann's H-theorem using the time-reversal symmetry of classical mechanics.

1883-1892 Picard and Vessiot extend Galois's methods to the theory of differential equations.

1885-1894      Federov, Schoenflies and Barlow independently derive the 230 crystallographic space groups.

1894      Curie analyses the relationship between the symmetry of cause and effect (Curie's Principle).

1894      Cartan classifies the compact semi-simple Lie Groups (following Killing).

1896-1905      Froebenius, Schur and Burnside develop the theory of group representations.

1905      Poincaré investigates invariance properties of Maxwell's equations (following Lorentz).

1905      Einstein introduces special relativity.

1909-1910      Cunningham and Bateman discuss the conformal invariance of Maxwell's equations in free space.

1916      Einstein announces the Principle of General Covariance.

1917      Kretschmann criticises the physical content of general covariance.

1918      Noether expounds the relationship between symmetry and conservation laws in Lagrangian theories.

1924      Polya and Niggli describe the 17 symmetry patterns in a 2-dimensional Euclidean space (these were actually known independently to Federov, 1891).

1925-1926      Weyl discusses the representations of compact semi-simple Lie groups.

1928      Dirac's relativistic wave equation leads to the discovery of the spin representations of the Lorentz group (the existence of spin representations of the rotation group was known to Cartan, 1913, and was exploited by Pauli in his theory of electron spin in 1927).

1932      Heisenberg introduces isospin space.

1935      Fock analyses the degeneracy of the hydrogen spectrum with respect to angular momentum as a dynamical symmetry.

1937      Kramers defines charge conjugation.

1939      Wigner investigates the infinite dimensional unitary representations of the Poincaré group (which is neither compact nor semi-simple).

1954      Yang and Mills introduce non-Abelian gauge groups in particle physics.

1954      Lüders proves the PCT theorem, i.e., invariance of field theories under simultaneous inversion of space, charge and time.

1956            Utiyama extends the works of Yang and Mills to derive Einstein's field equations from a principle of gauge invariance.

1956            Lee and Yang suggest non-conservation of parity in weak interactions of elementary particles.

1957            Fock publishes his 'Three Lectures on Relativity Theory'.

1961            Gell-Mann and Neeman independently introduce the SU(3) classification of the hadrons.

1961            Goldstone discusses spontaneously broken symmetries and the associated existence of massless particles.

1964            Fitch and Cronin carry out experiments which suggest that time-reversal symmetry may be broken by weak interactions.

1964            Gürsey and Radicati, and Sakita, introduce SU(6) as a mixing of internal and space-time symmetries in particle physics by analogy with Wigner's 1937 SU(4) theory in nuclear physics.

1965            Coleman and O'Raifeartaigh prove the impossibility of a relativistic generalization of SU(6).

1967-1968      Weinberg and Salam use a spontaneously broken gauge symmetry to unify weak and electromagnetic interactions.

1969            Bjorken introduces scaling symmetry in deep inelastic electron-proton collisions.

1970            Glashow invokes SU(4) symmetry (charm) to explain the non-existence of strangeness-changing neutral currents in weak interactions (charm was originally introduced by Bjorken and Glashow in 1964).

1973-1975      Glashow, Weinberg, Politzer and others develop theory of quark interactions in terms of colour gauge symmetry (chromodynamics).